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During this period, our work continued along several fronts, all related to planning and perception.

Prof. Drew McDermott and Michael Beetz, a graduate student, focused on transformational reactive plans, and especially the problem of inserting declarative goals into reactive plans. They were working on a paper summarizing their results, to be submitted to a conference.

Drew McDermott and Sean Engelson, a graduate student, worked on experimental testing of algorithms for map building in a mobile robot. The results are summarized in a paper submitted to the IEEE Robotics and Automation Conference.

Prof. Gregory Hager implemented a "first generation" algorithm for computing whether two or more objects could be placed together in a confined space. The algorithm is correct and complete for a class of unstructured objects, and maintains correctness for unstructured objects. It has been tested in simulation and on contours computed from real images. The same idea is extendable to many more sensor-based decision making tasks. He has also been working on fitting and making decisions about composite objects and multiple objects using the same constraint-based ideas. We have also managed to parallelize the algorithm using Linda.

At the same time, Hager's group has implemented two visual tracking systems. The first is a feature-based tracker that follows high-contrast boundaries. The second uses Michael Black's robust Horn & Schunk optic flow method to compute the motion of a small image patch. The latter is done hierarchically with the interesting property that the sampling rate is proportional to velocity. That is, the faster what is being tracked moves, the faster it is sampled, though at a lower resolution and hence lower accuracy.

In addition, Prof. McDermott worked on the problem of *anticipating perceptual confusion*. A robot that manipulates objects in the world must continually jump to the conclusion that two designators denote the same object, typically when the object it is looking for matches exactly one object in its immediate environment. In some cases the projector will be able to foresee that there could be more than one such object, and it will not know which one is correct.

One example of this bug is the "Bomb in the Toilet" problem (McDermott 1987). The robot is given two objects, exactly one of which is a bomb which will go off in a few seconds. It can disarm an object by plunging it into the toilet. Let us suppose that the robot can formulate the plan "Pick up the bomb; put it in the toilet" as a solution to its problem. Unfortunately, projection shows that the first step cannot be carried out, because no perceptual properties (e.g., color, texture) of the bomb are known. Two objects will answer to the description.

Another example arises in connection with trying to use a box to carry two or more identical objects. When the destination for the first is reached, the robot will begin taking objects out of the box until it finds an object that fits the description of the one it wants. The projector can easily see that in at least 50% of the cases the wrong object will be selected (depending on how many distractors there are).

These two bugs are not quite the same. In the first case, the problem will be manifest at run time. In the second, the plan would actually succeed (i.e., not explicitly FAIL), but the objects would be permuted in some way; only the projector can foresee the problem. The critic that derives a bug from the failure can, however, realize that the underlying source of the problem, masked by the presence of the box, is the same sort of perceptual confusion that underlies the "B-in-the-T" problem. Such a bug is characterized by a *target* object, a set of *distractors*, a *locus*, and a *confusion time*. The confusion time is the time point at which the target became irreversibly commingled with the distractors at the locus (a grid point or box).

There are several possible fixes for perceptual confusion:

1. Constrain the plan so that the current task to select the target precedes the confusion time.

2. Insert a step in the plan to move the distractors away from the locus prior to the confusion time.

3. Insert a step to mark the target in some way, and constrain this step to precede the confusion time. Use the information about the mark to pick out the correct object when necessary.

4. Alter the plan so that the operations that were going to be performed on the target object get performed on all the distractors as well.

Fix 1 is appropriate when the confusion is purely accidental; two plans that could have run sequentially get interleaved, and need to be pulled apart. Fix 2 is appropriate when the distractors do not really need to be at the locus. Fix 3 is appropriate when objects are easy to mark; if we had a way of painting objects in our world, this would be the right way to handle the box confusion problem. We have been focusing on formalizing Fix 4, because it is the only approach that will work for the B-in-T problem, and because it raises more interesting issues for the theory of plan transformation. A paper on this is in preparation,, to be presented at the AAAI Spring Symposium on Computational Considerations in Supporting Incremental Modification.

Activities:

Drew McDermott attended the IEEE conference on Systems, Man, and Cybernetics, Charlottesville, Oct.

Sean Engelson and Gregory Hager attended the SPIE conference on intelligent robotics systems, Cambridge, Oct.

In November, Drew McDermott gave an invited talk on "Transformational Planning of Reactive Behavior" at Ohio State University.

Also in November, Drew McDermott attended the DARPA Workshop on Transformational Scheduling, serving on the Technical Review Board.

Publications:

1. Sean Engelson and Drew McDermott 1991 Image signatures for place recognition and map construction. SPIE Technical Symposium on Advances in Intelligent Robotic Systems.

2. Sean Engelson and Drew McDermott Error correction in robot maps. Submitted to IEEE Conf. on Robotics and Automation, 1992.

3. Gregory D. Hager 1991 Towards geometric decision making in unstructured environments. In *Proc. 1991 International Workshop on Intelligent Robots and Systems*, Bellingham, WA, pp. 1412–1417.

4. Drew McDermott, William Cheetham, and Bruce Pomeroy 1991 Cockpit emergency response: the problem of plan projection. *Proc. IEEE Conf. on Systems, Man, and Cybernetics*, Charlottesville, Virginia

Overall Status and Plans:

We are quite happy with our progress so far. We are hoping over the next few months to pull our results together into a more tidy overall synthesis, especially in combining our model of robot navigation with our model of planning.

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
FACULTY SALARY	16,050	.00	21,822	21,822	-5,772
CLERICAL & TECHNICAL	8,000	5,493.32	3,442.65	8,935.97	-935.97
STUDENT ASST.	42,900	5,480.76	3,819.24	9,300	33,600
DIRECT WAGES	0	928	1,688	2,616	-2,616
EMP. BENEFITS	8,491	1,823.20	7,840.69	9,663.89	-1,172.89
D/P SUPPLIES	0	1,309	1,327.35	2,636.35	-2,636.35
D/P SVS.	12,000	0	0	0	12,000
D/P SOFTWARE	0	00	2,633	2,633	-2,633
FREIGHT & TRANSPORTATION	0	13.25	25.50	38.75	-38.75
PHOTOCOPYING	2,000	743.40	76.56	819.96	1,180.04
PRINTING	0	126	187.80	313.80	-313.80
MISC SERVICES		270		270	-270
TRAVEL (DOMESTIC)	4,000	444	1,230.35	1,674.35	2,325.65
OFFICE SUPPLIES	1,000	152.36	144.30	296.66	703.34
PERIODICALS	0	88.06	932.45	1,020.51	-1,020.51
TUITION REMISSION	21,513	5,053.32	0	5,053.32	16,459.68
HEALTH INS.		360		360	-360
TELEPHONE	1,000		49.81	49.81	950.19
DATA PROC. EQUIPMENT	83,000	20,580	13,880	34,460	48,540
INDIRECT (OVERHEAD 68.0%)	64,900	11,717.33	30,749.41	42,466.74	22,433.26
TOTAL:	264,854	54,582	89,849.11	144,431.11	120,422.89
		OVERHEAD ANTICIPATED:			48,742.60
		SPENDING BALANCE AVAILABLE AS OF 10/14/91:			71,680.29